# Fracture of andesite in the brittle and brittle-ductile transition regimes

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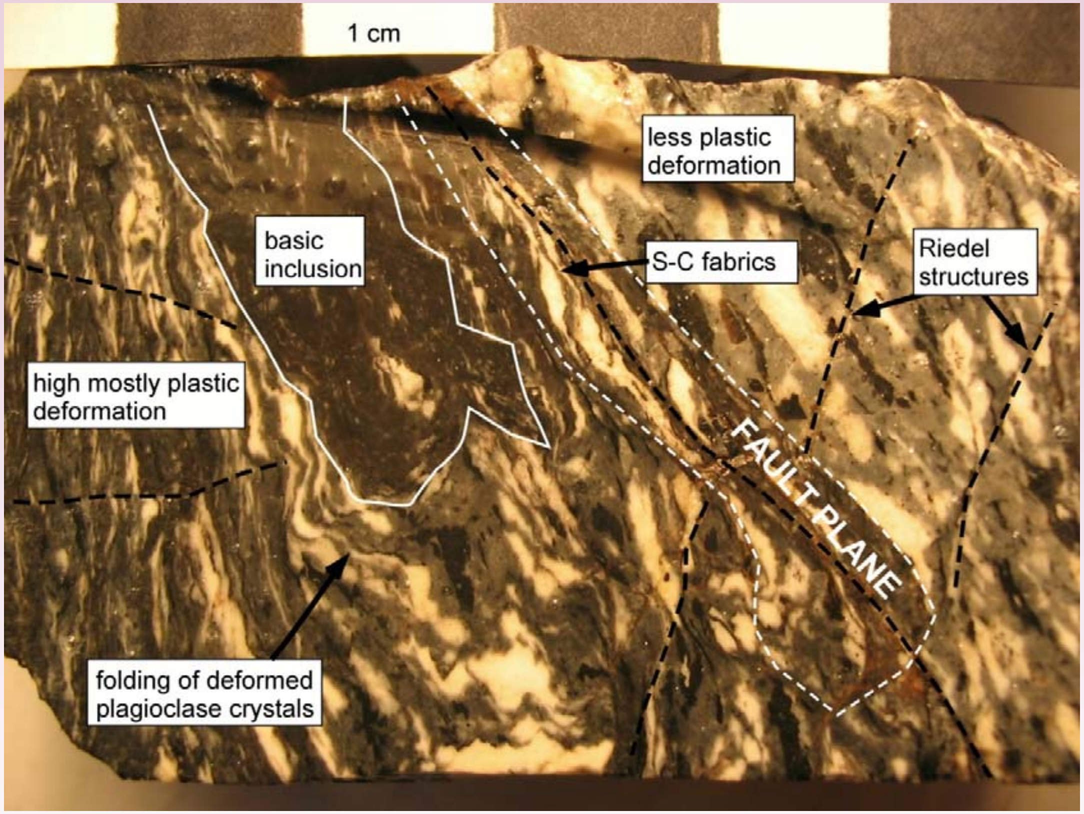
# Outline

- Why is it important to understand the fracture mechanics of andesite in the brittle and brittle-ductile transition regimes?
  - Evidence of widespread fracturing in lava domes, magma conduits and country rock in volcanic edifices
- How do we study this?
  - Description of experimental equipment and methods
- Experimental results
  - Strength and rheology
  - Acoustic emissions
  - Fracture surfaces
- Implications

# Fracturing of lava domes

Dome and spine complex at Soufriere Hills, Montserrat, Jan 1996


Extruding spine at Mount St Helens, USA, April 2006



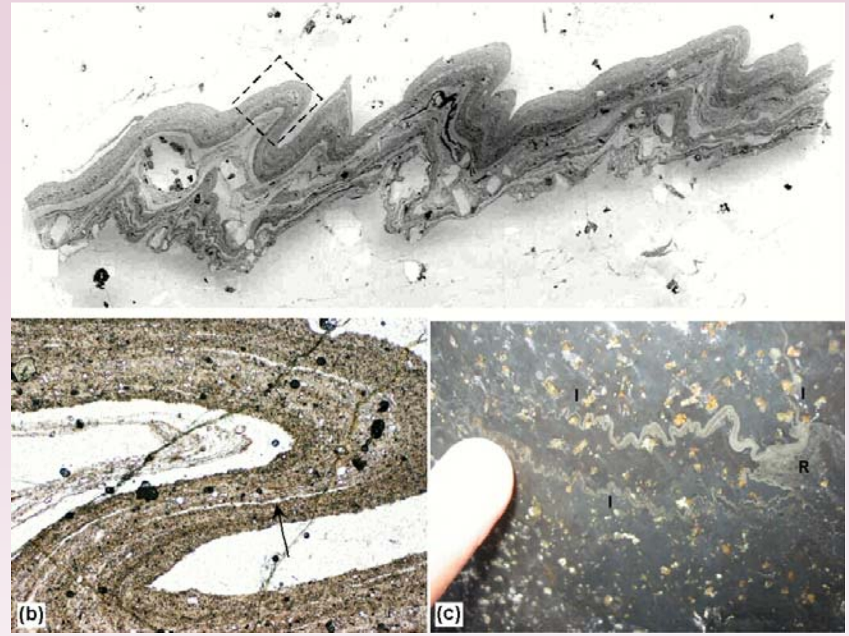

Lava spine from Unzen, Japan 1991 eruption covered in cataclasite (Nakada, 1999)

Brittle-ductile shear textures (Cordonnier et al., in prep.)

# Fracturing of magma conduits


Exposed rhyolitic conduit at Torfajokull, Iceland (from Tuffen et al., 2003 and Tuffen and Dingwell, 2005).

- ▪Networks of shear-tensile fractures in obsidian, ≤5 m long
- ▪Filled by obsidian ash with complex sedimentary structures
- ▪Flux of fluidised gas-particle mixture through fractures
- ▪Formed by shear fracture of lava

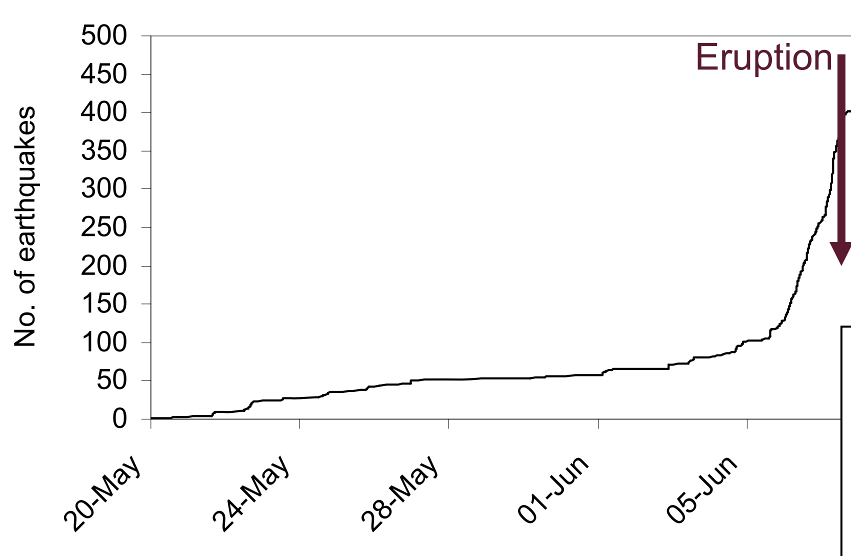




Fracture and ductile textures (Tuffen et al., 2003 and Tuffen and Dingwell, 2005)

- •Thorough sintering and welding – faults healed
- •Cohesive viscous deformation of healed cataclasite
- •Flow banding generated
- •Shows that faulting in eruptible magma

# Seismic observations




## Mount Pinatubo, Philippines, 1st eruption after long repose interval

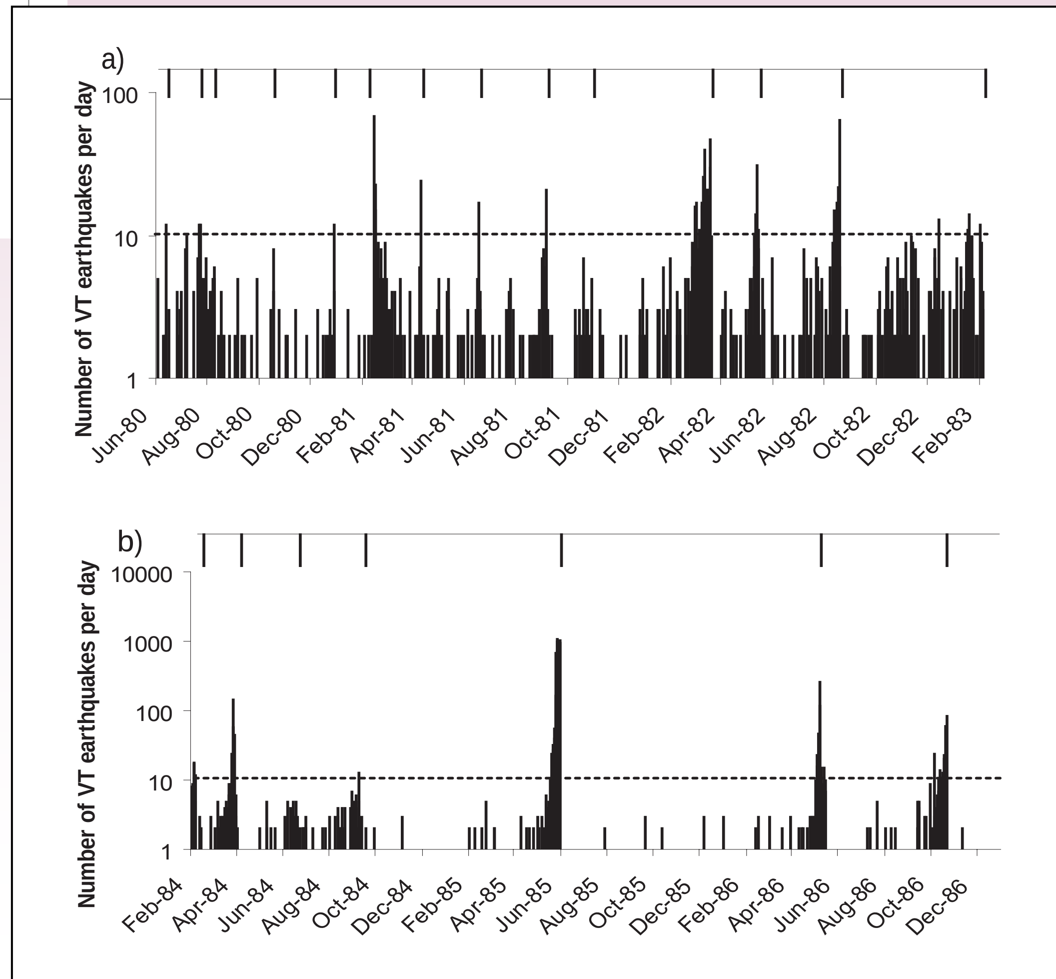
Cumulative earthquake count before the 7th June 1991 eruption, the first eruption after 500 years of repose

Earthquakes located within 5 km depth and 3 km lateral distance of the vent (Hoblitt et al., 1996)

## Mount St Helens, USA, lava dome growth

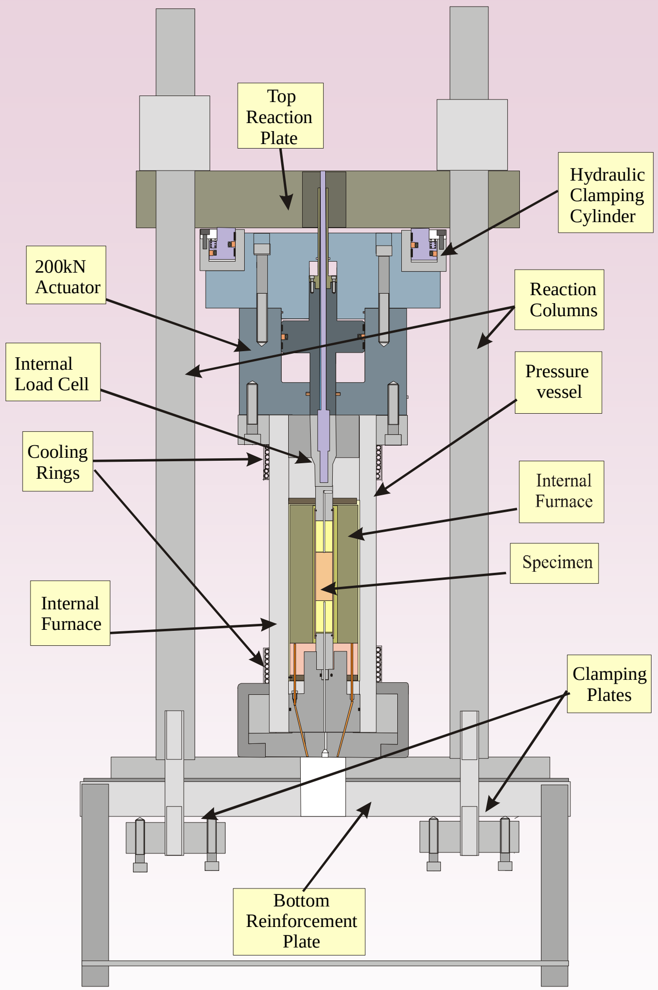
Number of earthquakes per day during six years of intermittent lava dome extrusion from from June 1980 until December 1986

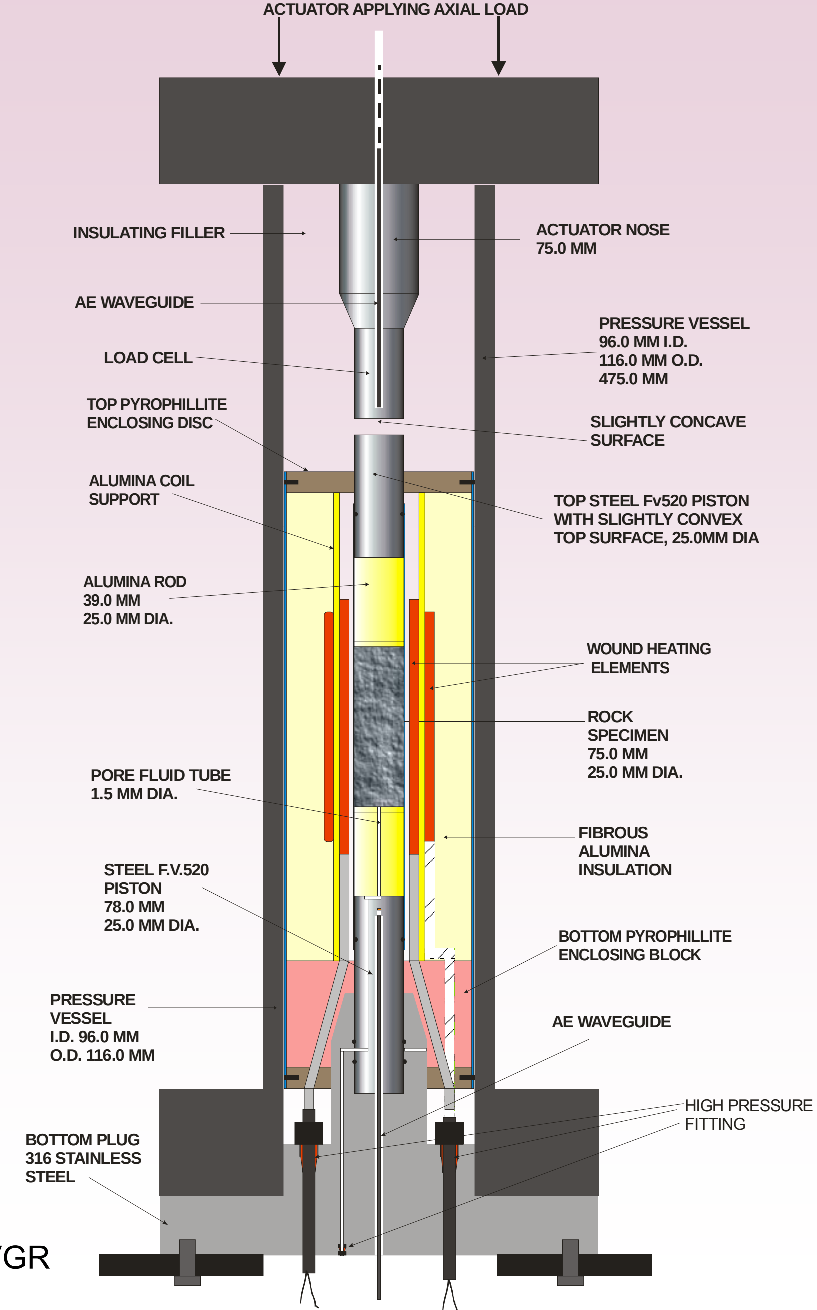
Earthquakes located within 2 km depth and lateral distance of the lava dome (PNSN)



# Laboratory Deformation Apparatus

UCL




Temperatures up to 1000°C

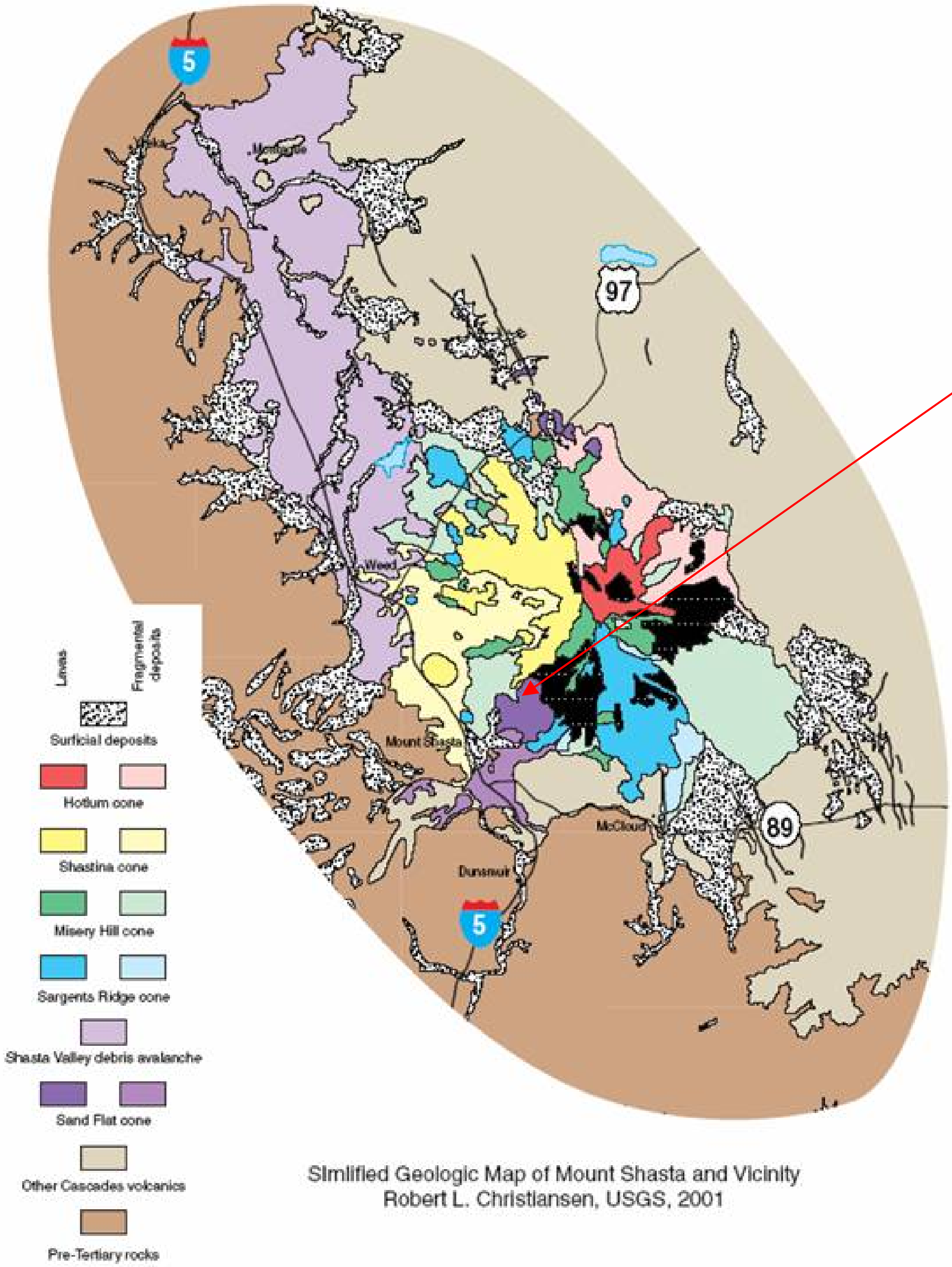
Confining Pressure up to 50 MPa

Axial pressure up to 450 MPa

Strain rate from $10^{-6}$ to $10^{-3}$

Rocchi et al., 2004, JVGR

# Ancestral Mount Shasta Andesite




Simlified Geologic Map of Mount Shasta and Vicinity
Robert L. Christiansen, USGS, 2001

Reasonably isotropic and homogenous andesite/ dacite with no distinct flaws required.

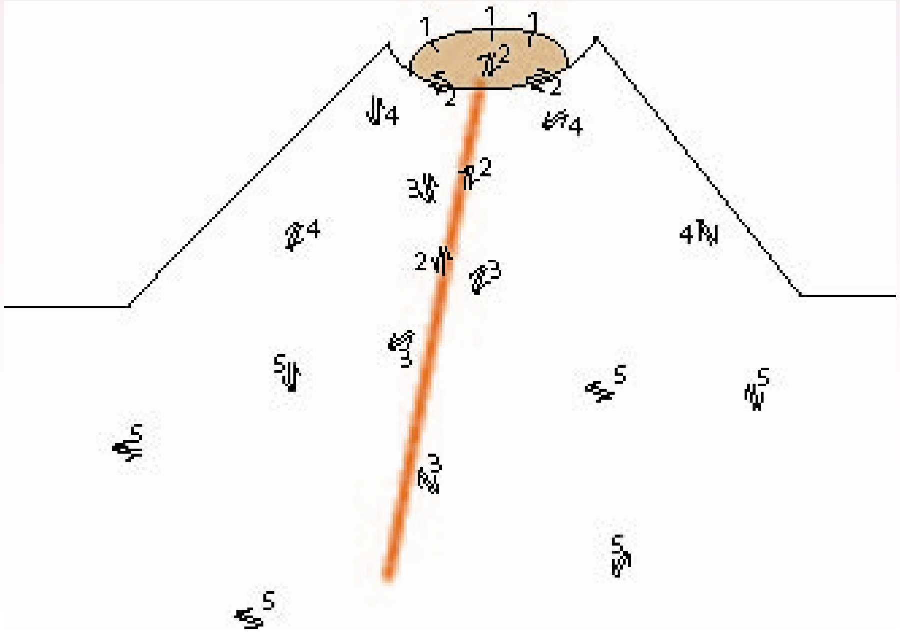
Ancestral Mount Shasta andesite from Northern California, USA, freshly exposed on road cutting.

Isotropic, porphyritic texture, 20% phenocrysts (<2mm), 7% porosity, <1% glass.

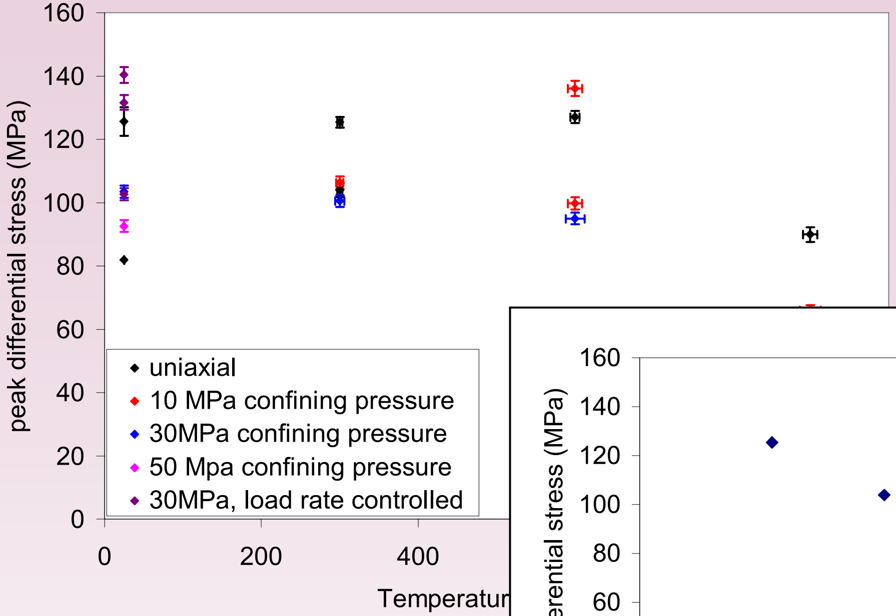
61.06% $SiO_2$, 18.19 % $Al_2O_3$, 5.59% CaO, 3.62% $Na_2O$, 2.33% MgO, 1.58% $K_2O$, 0.19% $P_2O_5$, <0.01% $SO_3$

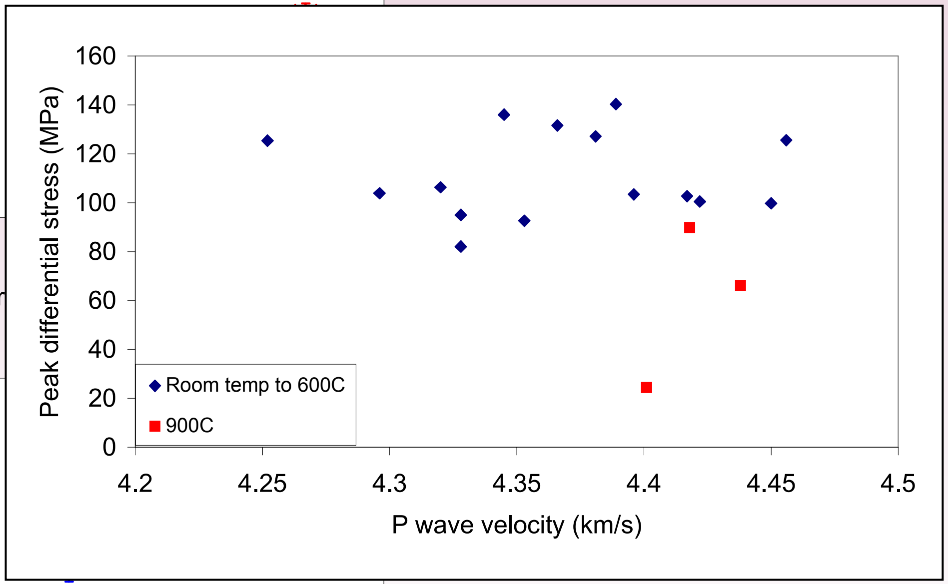
# Experimental Conditions

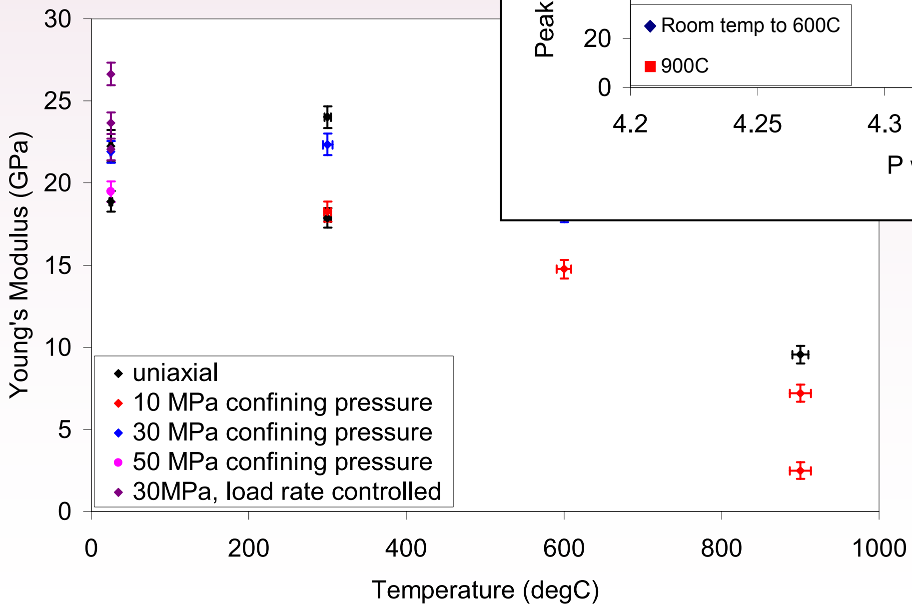
- $10^{-5}s^{-1}$ strain rate
  - this is within the typical rates of lava dome, conduit, and edifice deformation of $10^{-7}s^{-1}$ to $10^{-4}s^{-1}$ (Tuffen et al., 2003, Rust et al., 2003)
- Temperatures of 25ºC, 300ºC, 600ºC, and 900ºC
- Uniaxial and triaxial with confining pressures of 10 MPa, 30 MPa, and 50 MPa
- Dry with atmospheric pore pressure
- Nitrogen confining medium
- Recording AE



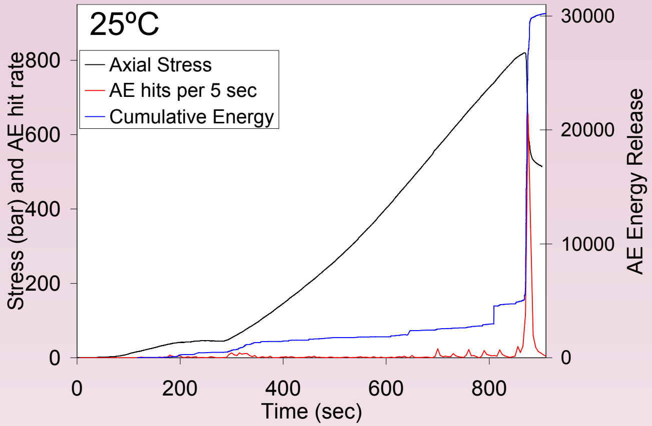
# Deformation of Ancestral Mount Shasta Andesite

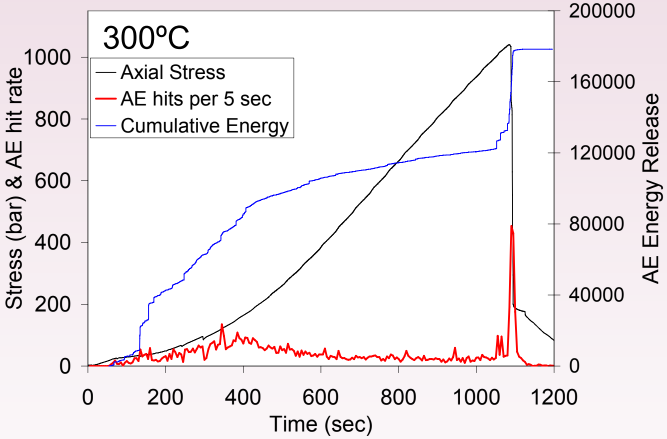


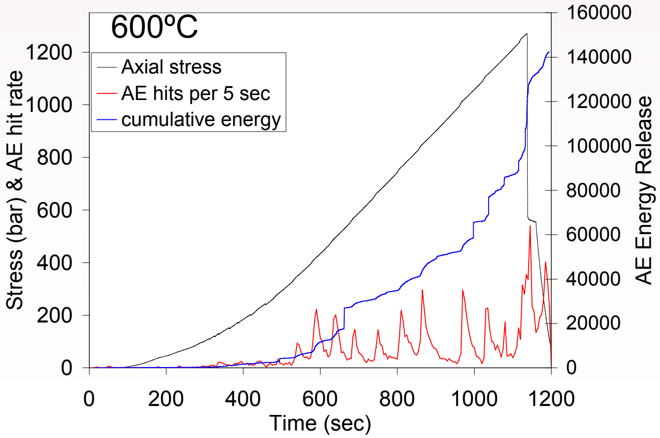



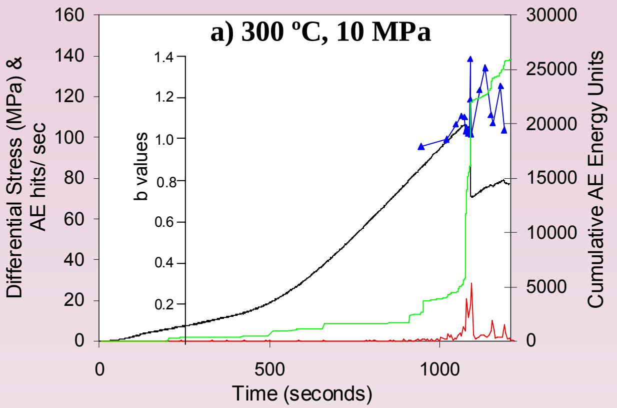
# Uniaxial Compression, brittle field

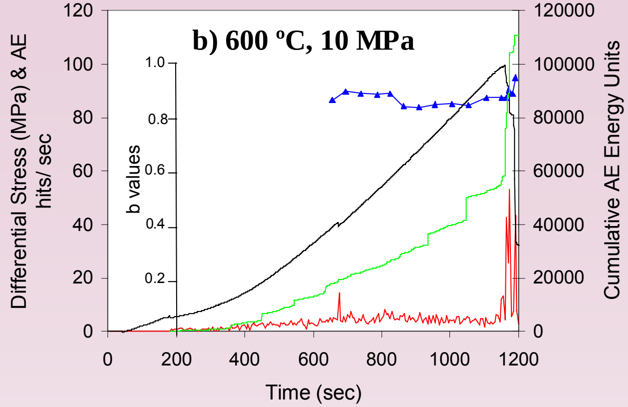


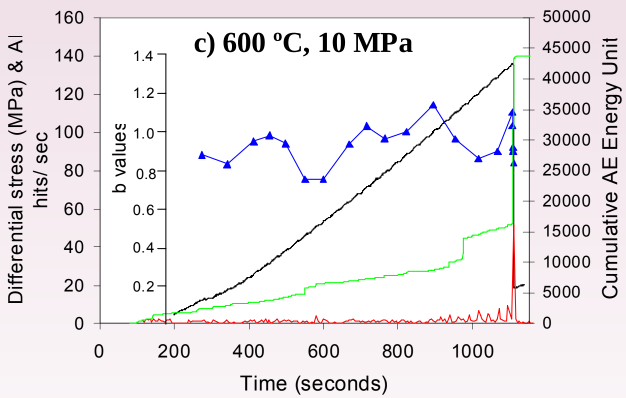



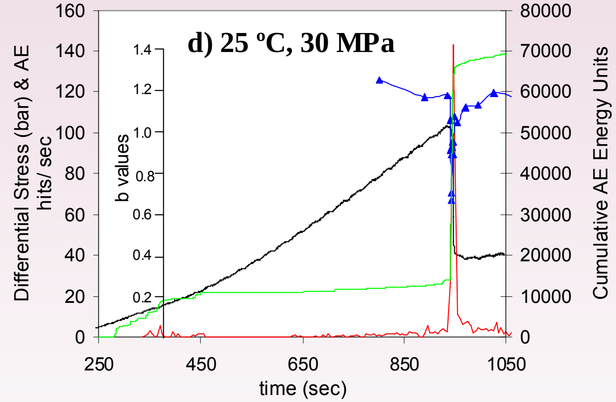

# Triaxial Compression, brittle field

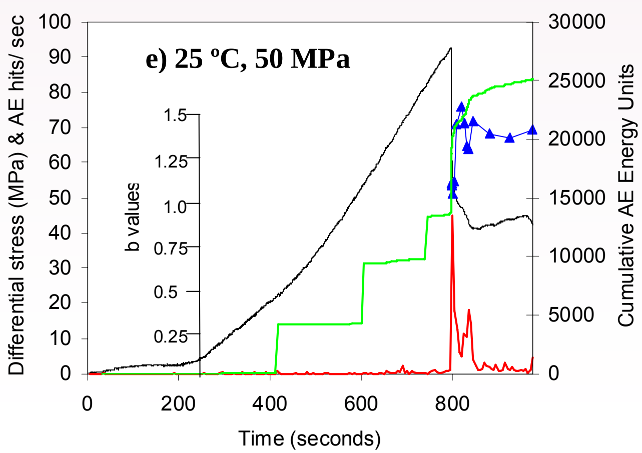



25ºC, 30 MPa



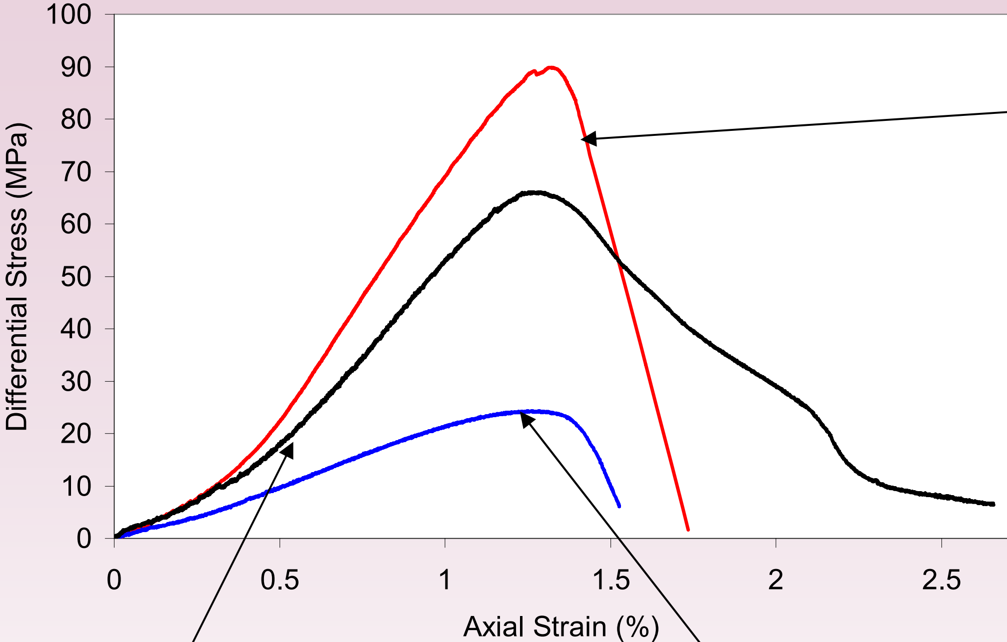




- Differential stress
- AE hit rate
- b values
- Cumulative AE Energy

600ºC, 10 MPa

# Uniaxial and triaxial compression in the brittle-ductile transition



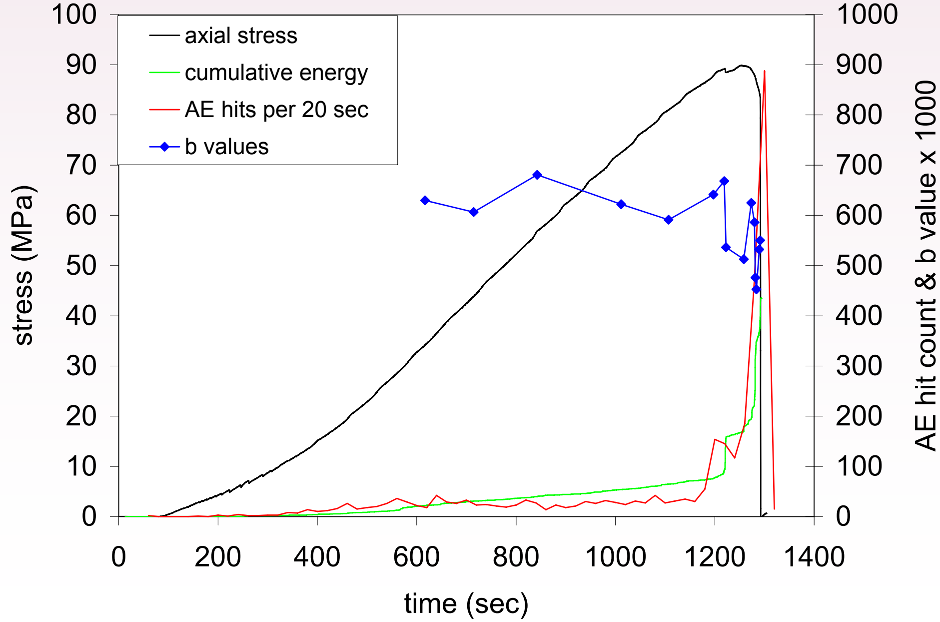

900ºC

Uniaxial compression

900ºC

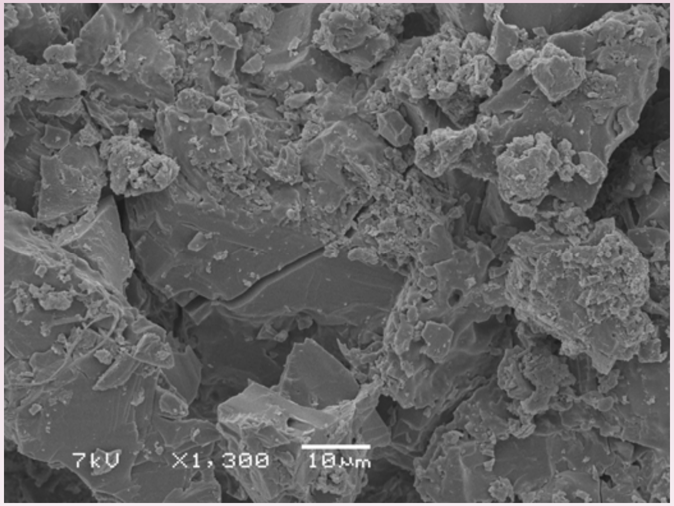
Triaxial compression

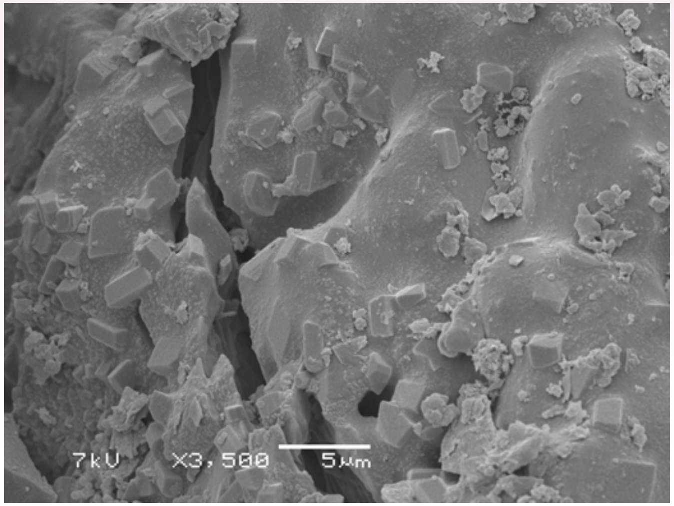
10 MPa confining pressure



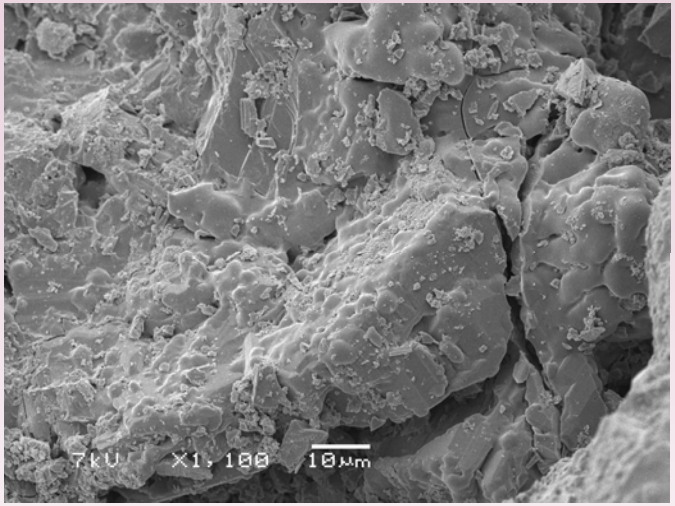
# Preliminary SEM results

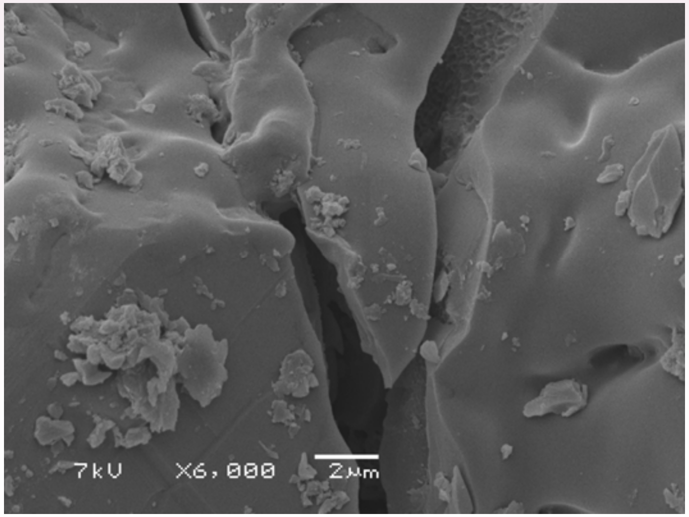
Brittle fracture surfaces




Brittle - ductile fracture surfaces



# Implications

- Flaws too small to detect in acoustic velocity measurements may dominate the strength of crystalline igneous rocks making it difficult to discern changes in rheology due to temperature or strain rate from sample variability
- AE precursors to sample failure were not consistent for similar or the same experimental conditions
  - The more consistent precursors seen before lava dome eruptions may relate to the interaction of more scales of cracking and/ or the magma feeding system geometry
- At the high strain rates observed in volcanic systems, earthquakes may occur in hotter material than that considered seismogenic in traditional earthquake science.
  - Andesite country rock within a volcanic edifice would have to be within 1-2m of the magma conduit to leave the brittle regime, especially if strain rates are high
  - Brittle shear fracture is a plausible source for hybrid earthquakes in volcanic conduits and lava dome systems

# Future Work

We are currently redesigning the high temperature triaxial deformation apparatus in order to achieve:

- Improved temperature control
  - In order to look more closely at changes in behaviour with small changes in temperature and strain rate within the brittle-ductile transition
- Full waveform recording of acoustic emissions
  - Improve insulation so cooling system that masks AE is no longer necessary
  - Embed AE transducers in pistons instead of at the end of long waveguides
  - These waveforms can then be compared to volcanic earthquake characteristics
- Measurement of permeability and acoustic velocities under different hydrostatic conditions and during deformation
  - Pore fluid inlets at either end of sample attached to permeameter

USGS/Cascades Volcano Observatory, Vancouver, Washington